The re-emergence of the Krill Harvesting Industry.

GCAS 8 Syndicate.

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Contents:

Introduction:

Krill Harvesting has been a fisheries industry since the 1970s and was at its height in the early 1980s. The rapid increase in Krill harvests during this time were a cause for much concern and a major reason for the formation of the Commission for the Conservation of Marine Living Resources (CCAMLR) in 1982.

Since then, CCAMLR has been the main governing body for the Krill harvesting industry but management practices have changed as scientific research has uncovered a basic lack of understanding of the effects removal of significant Krill biomass would have on the ecosystem.

Political influences and technological constraints have been limiting factors for the expansion of the Krill industry, resulting in season catches having not yet reached the total allowable catch set by the CCAMLR. In fact Krill harvests have not yet reached again the peak seen in the 1980s.

Increased market demand for Krill products in recent times has bought about the re-emergence of the Krill industry and as interest in this fishery has expanded so too has technology advancements and processing methods. The increase in Krill Harvests that these technology advancements could bring, coupled with an increased market demand, show a trend towards higher and higher levels of Krill extraction from the worlds oceans.

This paper will focus on the harvesting of Krill in the Southern Ocean and how this relates to potential issues needing to be examined in the future.

Krill Fisheries Context

The Southern Ocean

Located south of the Antarctic Convergence Zone which roughly equates to south of the latitude of 65 degrees south. This region is defined by areas of large biomass that was largely unexploited until the early 1900's. Recognition of the potential of this area has been ongoing since the early explorers of the 17th and 18th century. However, exploitation of the marine resources to be found in the Southern Ocean has been limited by political, technological and biological factors as well as the physical constraints of the locality itself.

History of exploitation of marine resources in the Southern Ocean

Harvesting of Marine resources in the Southern Ocean was initiated in the early 1800's as sealing vessels moved south to explore the seal islands described by Cook during an expedition through the South Shetland Islands in the late 1700's. By the 1900's seal populations were significantly reduced and sealing ceased in the mid 1900's. Any continued sealing is now controlled by the Convention for the Conservation of Antarctic Seals (CCAS). Whaling was also carried out from the late 1800's and reached its peak in the 1930's. Whale populations were decimated, species by species, and now very little whaling is carried out in the Southern Ocean due to International whaling commission (IWC) restrictions.

Sealing expeditions were at the forefront of Antarctic exploration and much scientific work was carried out in synchronisation with the commercial harvesting of seals. Early harvesting in the Southern Ocean did not include the mass removal of fish for commercial reasons and it was not until the 1900's that the fish resource was being recognized as being economically viable. As Sealing and Whaling potential was reduced many industrial fisheries turned toward other species found in the Southern Ocean.

Krill Fisheries Development

Krill was not considered an important element in the Southern Oceans until the mid 1900's. Mostly this was due to a scientific bias towards species that were seen as being economically viable. It was not until exploration of Krill as a resource was conducted, mostly by the former Soviet Union and Japan in the 1960's and 1970's, that it was generally accepted that there were potential economic gains to be had by the harvesting of Krill. Significant research on the biology of the Krill was conducted by the Discovery committee for the British government in the inter war years. This was conducted over a series of studies on whales which are dependent on Krill as a food source and so the biology of Krill was also covered. Evaluation of the Krill resource at this time estimated a sustainable yield of 150 million tonnes per season[1]. This represented a phenomenal amount of sustainable biomass able to be exploited.

The preliminary exploration of Krill as a resource occurred in the 1961/62 season during which a Russian vessel named the Muksun caught 4 tonnes of Krill for research along with other vessels from the USSR[2]. The Japanese Marine Resource Research Centre (JAMARC) also operated around this time to better understand the potential of Krill as a resource. Krill harvesting was explored as a potential cheap abundant food and protein source. The Japanese programme of Krill exploration and research was fully active by the early 1970's, during which JAMARC vessels caught 59 tonnes in the 1972/73 season[3]. During the initial stage of Krill harvesting, methods were varied both in technique and effectiveness. Due to the lack of knowledge on Krill behaviour methods to capture and process Krill were experimental and somewhat "unorthodox"[4]. In the 1975/76 season a West German expedition on the *FFS Walther Herwig* set out to develop fishing techniques for Krill harvesting and location. By the end of this

[1]Eddie, G.O., *The Southern Ocean: The Harvesting of Krill* (1977)
[2] Ibid.
[3] Ibid.
[4] Ibid.

season catches from this vessel were large enough to suggest an economically viable catch level. However, the information gained up to this point on Krill meat as a resource for human consumption implied that the key to Krill fisheries was in processing methods on board the ship to in intermediary or final product[5]. Processing in the form of, at least, de-shelling was vital within the first 2-3 hours of catch, to prevent fluoride from the shell contaminating the meat[6]. In the 1977/78 season the first "factory mother ship with attendant catchers" was sent down to the Southern Ocean by Japanese fishing interests[7].

Industrial fisheries were also harvesting Krill by this stage as new products such as fish meal, frozen cooked and raw whole Krill and peeled tail meats were being tested for general consumption in the Soviet Union and Japanese markets. The increase in product use for Krill harvests had a significant effect on the economic interest in Krill harvesting and in 1981/82 season Krill harvesting reached its peak with removal of 528,201 tonnes of Krill[8]. By the 1980's interest in the way Krill was being harvested and used was beginning to involve thoughts on management criteria for this new fishery[9]. In 1982 after debate from the late 1970's the Commission for the Conservation of Marine Living Resources (CCAMLR) Came into force in response to the need for a governing body for the removal of marine resources from Southern Ocean and Antarctic waters.

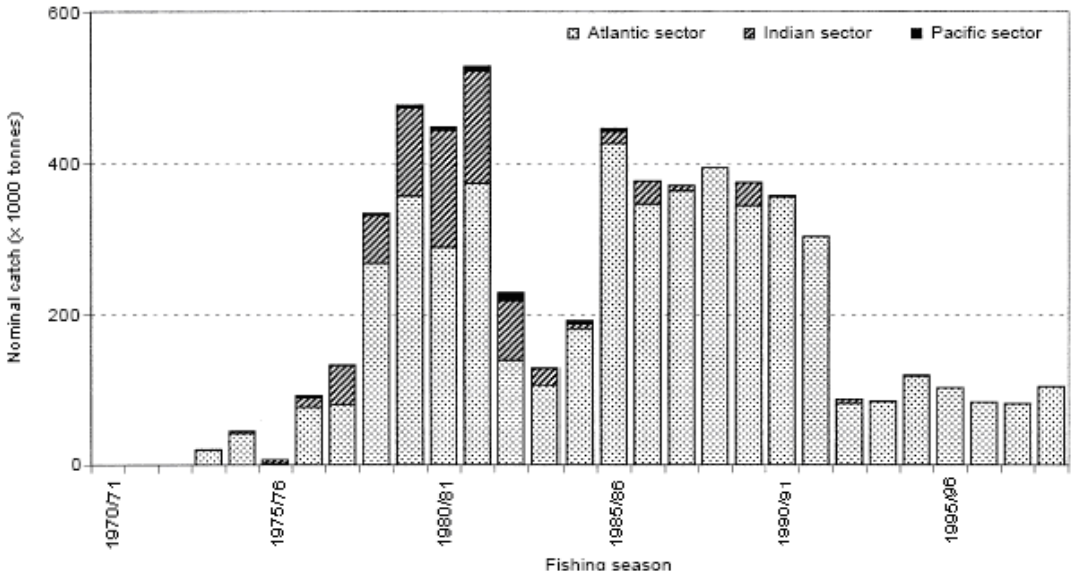
Political Context

The commercial Krill industry developed, mostly in the 1970's and 1980's, as a response to the need for a cheap abundant food source. This demand came, mostly, from the Soviet Union (communist Russia), Japan and Chile. These markets were particularly interested in Krill in the Southern Ocean as a potential

[5] Report of the 1975/76 Antarctic expedition of the federal republic of Germany: *Research and exploration of the resources of Krill and food fish in the Antarctic* (1977)
[6] http://www.lighthouse-foundation.org/
[7] Eddie, G.O., *The Southern Ocean: The Harvesting of Krill* (1977)
[8] http://www.ccamlr.org/
[9] Mitchell, B. and Sandbrook, R., *The Management of the Southern Ocean* (1980)

resource as it represented a large, unregulated biomass that was a significant protein source as well. With Krill representing a major link in the ecosystem of the Southern Ocean concern at the potential increase in Krill harvesting continued to build from the 1970's till its peak in the 1980's with the formation of Commission for the Conservation of Antarctic Marine living Resources (CCAMLR). This Commission was created in response to harvesting of resources in the Southern Ocean at rates which, if allowed to continue to increase unregulated, would have a profound impact on the existence of the marine life in the Southern Ocean. At the time of formation CCAMLR predicted a continuous rise in Krill harvests. Predictions of millions of tonnes worth of catches were used as indicators of a future, unsustainable fishery with the unknown effects of this on the ecosystem as a whole creating concern in countries with Southern Ocean interests. Ecological interest in the recovery of the Baleen whale populations created concern of the effect reducing baleen whale food sources would have on the long term continuation of these species. (See Figure 1[10])

Figure 1



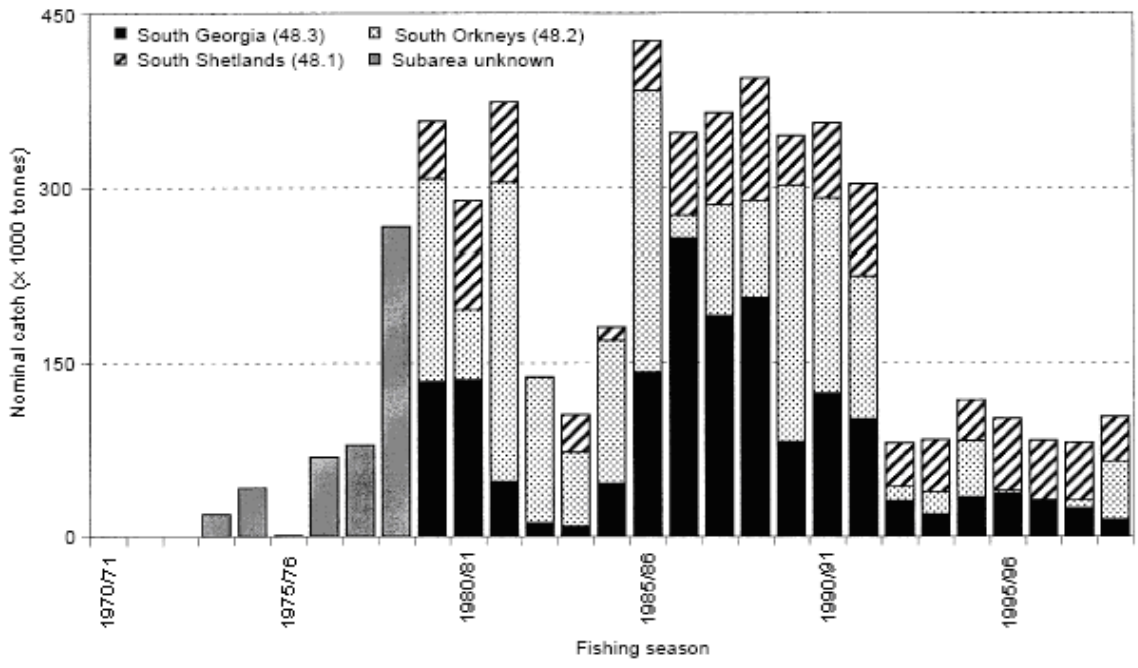
Nominal catch of krill (*Euphausia superba*) in the Atlantic Ocean (Statistical Area 48), Indian Ocean (Statistical Area 58) and Pacific Ocean (Statistical Area 88) sectors of the Southern Ocean.

[10] http://www.ccamlr.org/

However; despite the predictions of an increasing demand for Krill resulting in larger and larger catches, the trends in catch levels in the early 1990's changed from steadily increasing to a sudden drop in harvesting levels.[11]

This drop in harvesting represents the fall of Communist Russia and the lack of demand this created as one of the largest Krill markets was no longer involved in the harvesting and consumption of Krill. This lack of demand for Krill products impacted harvesting levels and, as the Soviet Union was no longer involved in Krill harvesting, one of the largest fleets of harvesting vessels was also removed from the industry. Ironically it was not until 1991 that CCAMLR made any move to regulate Krill harvesting with the placement of a 1.5 million tonne limit on the South Atlantic, the dominant area of Krill harvesting[12]. (See catch figures for this period in Figure 2[13])

Figure 2



Nominal catch of krill (*Euphausia superba*) by statistical subarea in the Atlantic Ocean sector.

[11] http://www.ccamlr.org/
[12] Stevens, J.E., *The Secret lives of Krill* (1995)
[13] http://www.ccamlr.org/

Strangely, this was then followed by a restriction of 390,000 tonnes on the South Indian Ocean which showed now evidence of Krill harvesting at the time[14]. (Note South Indian Ocean Krill proportions on previous page graph)

Current State of Krill Harvesting

It has not been until recently that demand for Krill has increased. This is due mostly to the reenergizing of the Krill market as a result of new products made from Krill. The Krill harvesting industry at present time is largely dominated by Japan which has continued its Krill harvesting industry throughout its development. (See Figure 3[15]) Japan continues to harvest over half of the total season catch although more recent data shows an increase in interest from Korea and the Ukraine.

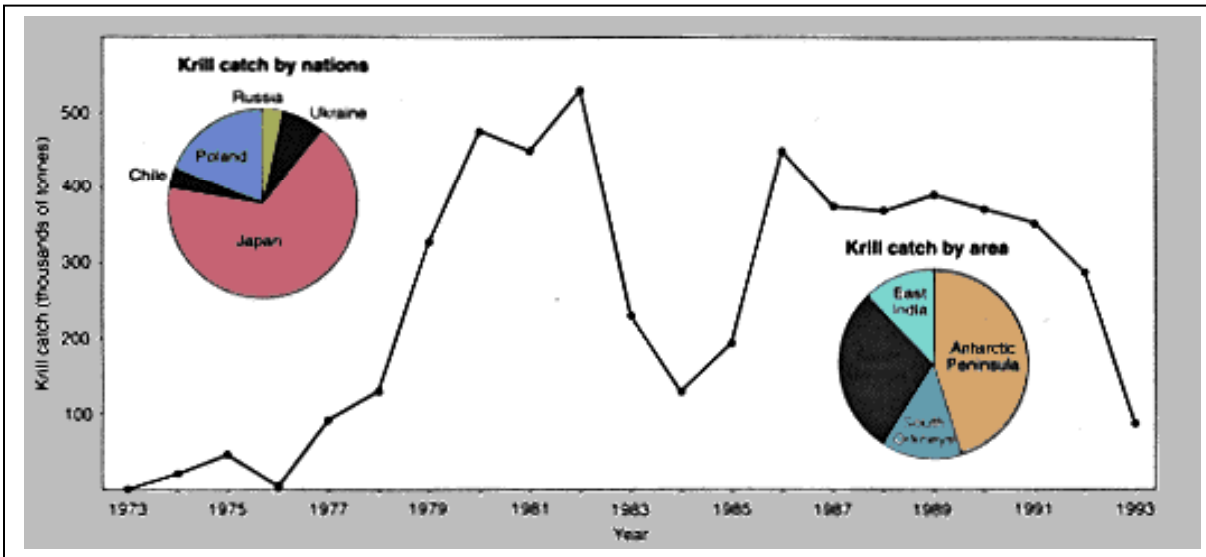


Figure 3

Krill Harvests currently vary around 100,000 to 160,000 tonnes. With a CCAMLR total allowable catch limit set at 4 million tonnes[16].

[14] Stevens, J.E., *The Secret lives of Krill* (1995)
[15] www.doc.ic.ac.uk/~kpt/terraquest/va/ecology/ecology.html
[16] Clark and Hemming, *Problems and Prospects for the Convention on the Conservation of Antarctic Marine Living Resources Twenty Years On* (2001)

Legal Context.

Due to the complex nature of social relationships between States, International Law is seen as a necessary tool in providing a framework for which to manage their dealings. CCAMLR is one of the five instruments that make up the bundle of international legal documents which manage the Antarctic Region. As the 1959 Antarctic Treaty was seen more as a tool to bring about political stability, further conventions were required to deal with specific environmental issues which have later been brought to light. Concerns in the 1970's as to the over harvesting of Krill, which was seen as a linchpin of the Antarctic ecosystem, was one such issue which lead to the development and ratification of CCAMLR.

International Law

International Law is the law that governs relations between entities (States) which have legal personality (the capacity to act in an international arena). International Law attempts to regulate and codify common actions in which there are relationships between one or more States. International Law, however, is not enforceable unless it has been implemented by the individual State at the domestic level. Therefore, International Law is a decentralised organisation where decisions are made through negotiation and agreement only. A State cannot be bound by International Law unless they have first agreed to be so bound and they have taken steps to legislate these international agreements internally. In an international setting, all States are independent and sovereign and therefore equal in an international setting. Laws are only enforceable domestically, not internationally.

Criticisms of International Law are that it really is only a form of morality. There is no central authority for which to enforce laws. The General Assembly is like an individual States parliament however, it has no binding power to enforce or police

any breaches. There are also no means of compulsion other than international censure and political pressure by the other agreeing parties.

Disputes at an International Level

There are dispute resolution procedures under International Law. A claim can be brought under the International Court of Justice (ICJ) or an International arbitration tribunal could hear the claim and make a ruling on the situation at hand. However, parties can chose whether they will allow such a decision to be made and no decisions are binding on the parties. The State can chose whether or not to abide by any ruling. Moreover, International Law is characterised more by its observation than its breach.

Sources of International Law

Internationally law is, however, an integral aspect of international relations between States. International Law represents common practices among States. Shipping laws and common etiquette for behaviour whilst on the high seas is a long standing customary practice that International Law has merely codified. There are many sources of International Law. Generally, treaties, which are established, written rules reached by consensus between States, are the most enforceable and recognized form of International Law. Treaties are a source of obligation between the signatories and it provides mechanisms for amendments and breaches to the treaty.[17]

Development of Antarctic International Relations

After the age of discovery and exploration, which ended in the early 1900's, there were multiple claims of sovereignty over the Antarctica Continent. Antarctica became a political minefield with seven States claiming sovereignty over sectors

[17] Treaties are also known as conventions or international instruments.

of the Continent based on prior discovery or sightings made over the last three centuries. Other States believed that they also has the right to make a claim over the entire Continent if they so chose to do so.[18]

The 1959 Antarctic Treaty

The Antarctic Treaty, which was established in 1959, was seen as a political compromise to enable activities on the Continent to progress whilst signatory States still maintained their prior position. It for all intense purposes froze the position so the States could get beyond the territory claims and cooperate together for mutual benefit and the greater good of science. Fundamental rules and procedures were agreed to by signatories to promote scientific cooperation for peaceful purposes.[19] The Antarctic Treaty forms the foundation of the bundle of legal instruments, which organise and govern activities in the Antarctic. Although there were only 12 initial signatories there are now 28 consultative parties (voting rights) and 17 acceding States to the Antarctic Treaty.

The Antarctic Treaty System

Because the original 1959 treaty, which was enforced in 1961, was primarily a political compromise further conventions were later added to cover environmental issues. There are five main instruments, which form the Antarctic Treaty System (ATS). The Antarctic Treaty, Agreed Measures for the Conservation of Antarctic Flora and Fauna (1964), Convention for the Conservation of Antarctic Seals 1978 (CCAS), Convention for the Conservation of Marine Living Resources 1982 (CCAMLR), Convention on the Regulation of the Antarctic Mineral Resource Activities 1984(CRAMRA) – negotiated but never signed and The 1991 Protocol to the Antarctic Treaty on Environmental Protection.

[18] Davidson JS, *Antarctic Legal Environment* (2000)
[19] The main body of this is outlined in Article 4 of the Antarctic Treaty 1959

CCAMLR

CCAMLR was established in 1982 after concerns in the 1970's about the fishing and harvesting of Krill. Krill is the primary source of food for the majority of Antarctic wildlife. Seabirds, seals, penguins, fish and whales all enjoy Krill as part of their staple diet. There was a fear that unfettered exploitation could potentially affect the whole Antarctic ecosystem. Signatories to the Treaty agreed to CCAMLR so that the parties could protect their interests and safeguard the natural marine resources in the Southern Ocean represented as south of the Antarctic Convergence. Moreover, this convergence of waters was used as a boundary because it acts as a natural barrier protecting the closed Antarctic ecosystem.

Six of the 33 CCAMLR Articles link back to the ATS. The object of the convention was to both conserve and permit rational use of marine living resources. To meet the objects of the convention extensive research and information needs to be collected to ascertain effects of fishing or other behaviours in specific areas covered under CCAMLR. From this information, CCAMLR relies on scientific advice as to the biomass of certain desirable species. This is seen as a precautionary approach because research is still in the early stages and biomass is, to a degree, undetermined. To balance its role as both conservationist and rational use regulator, scientific advice is required to determine total catch numbers.

CCAMLR works in conjunction with other conventions such as CCAS and the International Convention for the Regulation of Whaling (ICRW). It covers all other marine living resources that fall outside their mandates such as fish, crustaceans, marine organisms and sea birds. Regulations as to catch numbers are in place to try to prevent certain species from being fished out. Currently Toothfish fishing has a strict quota and licensing procedure. Independent inspectors are also required on the vessels to ensure compliance. Methods of fishing such as bait

types and descent rates of line release are regulated to minimize sea bird fatalities. Catch documentation is also required to be able to on sell their catch. This measure was implemented to stop illegal catches being sold and to deter the unrestricted exploitation of Patagonian Toothfish

Although CCAMLR was initially established because of fears of over fishing and harvesting of Krill, regulations as to Krill harvesting is minimal. There are currently precautionary catch limits set for Krill based on a survey carried out in area 48 by CCAMLR licensed fishing vessels that was conducted at the start of 2000. By placing catch limits CCAMLR endeavours to ensure future sustainability of Krill. Reliable scientific data due to the unregulated nature of Krill fisheries has not yet been collated. The true impact of Krill exploitation is therefore unknown. Unlike Toothfish fishing, which has scientific observers and data collection requirements this, is largely unmet concerning Krill. Because regulations can only be implemented by way of consensus between the parties further efforts to place international observers on Krill vessels has not been meet with consent be all signatory parties.[20]

Enforceability of CCAMLR

Like any other International Law, a State cannot be bound by a treaty or convention unless they have agreed to be so bound. Therefore not all parties to the Antarctic Treaty have chosen to be signatories or members to CCAMLR. Currently there are only 24 commission members with voting rights and a further 8 acceding States. All decision-making and regulation setting is based on consensus of all signatory parties. Enforcement of such regulations, however, is problematic because it is up to the individual State (or flag nation) to police and enforce the rules on its own vessels. Because levels of domestic legislation and its extra territorial reach are inconsistent between signatory States, it is often

[20] Clark and Hemming, *Problems and Prospects for the Convention on the Conservation of Antarctic Marine Living Resources Twenty Years On* (2001)

difficult to police and enforce breaches. Therefore, many breaches go unpunished and political pressure and censure of other signatory parties is the only real way of preventing or deterring further breaches. Countries such as New Zealand, Australia and the United Kingdom patrol their claimant territory by sea and air. However as they are by and large controlled by the Law of the Sea (UNCLOS) which forms the basis of CCAMLR enforcement rights, they have no jurisdiction on ships flagged by other countries and ships that have not departed from one of their respective ports. Therefore, third parties, which are not signatories to CCAMLR, are not bound by the increased regulations that CCAMLR place on the Antarctic region. Vessels, which are also flagged under a different signatory to the ATS, have the jurisdiction to police and enforce licensing rules on their own vessels so are not obliged to allow other countries who patrol the water the ability to board and enforce CCAMLR on vessels flying their flags.

Illegal, Unregulated and Unreported (IUU) Fishing

Due to the economic gains associated with certain types of fishing down in Antarctic waters there is a certain amount of IUU fishing occurring in CCAMLR territory. At present IUU is not a prominent concern with regard to Krill harvesting. Because Krill is unregulated and the economic gains are minimal, IUU fishing is not deemed lucrative. However, this is subject to change if the economics of the situation change.

The tight regulations required under CCAMLR can be restrictive and costly to vessels therefore, cowboys wishing to make a quick buck will fish outside CCAMLR rules and regulations. As Stated earlier in regard to enforcement of CCAMLR it is up to the licensing or flag State to police and enforce their own vessels. Countries that have a more lax domestic fishing régime or a limited extra territorial reach become attractive and lucrative ports to be licensed under. Political pressure by way of censure can be used to embarrass a State when it

can be shown that one of their flagged vessels is operating illegally down in the Antarctic region. Vessels however, that are flagged by a non ATS member are not bound by CCAMLR regulations at all.

The fishing industry itself has made steps to stop IUU fishing. Non Governmental Organizations (NGO's) such as the Collation of Legal Toothfish Operators (COLTO) actively name and shame known IUU operators. They operate a website that records all suspected IUU operations. Details such as the time, place and destination of suspected IUU activities are recorded for all other operators and port authorities to see. Such campaigns act as a deterrent to more than just illegal tooth fishing. Where there is suspected illegal fishing in one body of water it can be assumed that other illegal fishing has been carried out in other countries EEZ. Under UNCLOS, vessels can be seized if in the EEZ waters of countries when it is believed that illegal fishing has occurred within their waters.

IUU fishing may not be problematic regarding Krill at present but if the industry booms it could become an issue. Because of the importance of Krill in the ecosystem IUU fishing represents an unknown and unmanaged take of an important Southern Ocean species.

Antarctic Krill Biology as it relates to the re-emergence of the Krill fishing industry.

Krill in the Southern Ocean

Krill is the common name for the shrimp-like marine invertebrates of the family *Euphasiid*. Several species of the small crustacean can be found in the Southern Ocean including *Euphasia superba, E. vallentini, E. triacantha, E. frigida* and *E. crystallorophias*[21]. The species of particular interest to the fishing industry is *Euphausia superba*, the Antarctic Krill. This species forms large swarms in the upper layers of the open ocean during the summer months. The swarm sizes vary from metres to kilometres and they can be so dense that they give the ocean surface a reddish appearance. Estimates of density based on echo sounder measurements in conjunction with net hauls give a range from 1.5kgm^{-3} to 33kgm^{-3} with the average being around 6kgm^{-3} [22]. It is these swarms that are the target of fishing vessels.

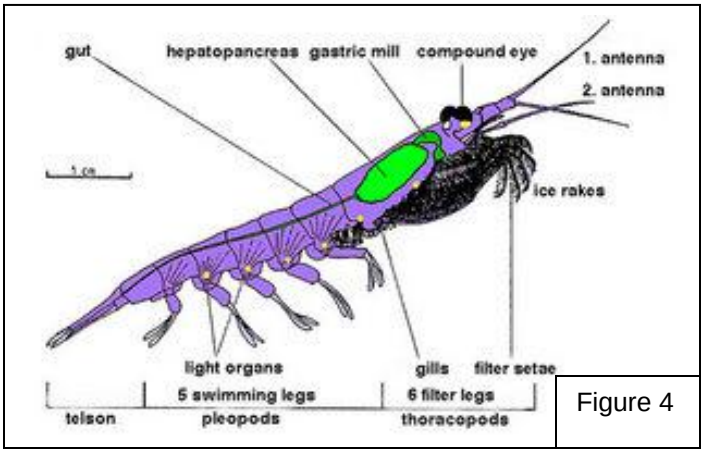


Figure 4

As Krill are crustaceans and have an exoskeleton made up of three segments: the cephalon (head), thorax, and the abdomen. The first two segments are fused into one segment. They have compound eyes, two antennae and several pairs of thoracic legs including the feeding and grooming legs. They also have five sets of legs called pleopods which are important for

[21] Gascon, V., Werner, R., *Antarctic Krill:a case study on the ecosystem implications of fishing* (2005)
[22] Laws, R.M., (ed). *Antarctic Ecology* (1984)

swimming.[23] The adult *E. superba* has a wet weight of about 1g and a length of up to 6cm making them one of the larger species of *euphausiids*[24]. They feed mostly on phytoplankton though they are no longer considered herbivores as they do appear to feed also on the small zooplankton. Krill are often put into the same group as zooplankton but this designation is deceiving as the Krill are free swimming, not confined to the motions of the ocean currents as is the case with most of the tiny plants and animals representing the plankton. Krill hold a position of importance in the Southern Ocean food web. They are the largest converter of biomass from the primary producers, the phytoplankton, to the large carnivores of the region, seals, fish, squid, seabirds as well as the baleen whales which migrate south to feed over the southern summer[25].

Life cycle of the Antarctic Krill

The Krill life cycle begins with spawning during the Antarctic summer. A female Krill may release 2000 eggs into the water column per brood and it is believed that the Krill spawns not once a season but many times over a five month spawning season[26]. The egg sinks hundreds of metres below the surface and hatches. The larva that emerges has 6 legs and no mouth and feeds off its yolk sack as it begins the climb towards the surface. Over a period of two to four weeks the larva undergoes 3 moults emerging as the calyptopsis with fully operational mouth and feeding appendages. Now living on phytoplankton the spidery calyptopsis undergoes another series of three moults to become a furcilia and then after another six stages and moults emerges as a juvenile Krill. This whole process may take four months if there is plenty of food available or as long as nine months, particularly if maturation is occurring over the winter with lower temperatures and significantly less phytoplankton for feeding[27]. At this point the

[23] http://en.wikipedia.org/wiki/Krill
[24] Nicol, S, de la Mare, W, *Ecosystem management and the Antarctic krill* (1993)
[25] ed. Everson, I., *Krill: Biology, Ecology and Fisheries* (2000)
[26] Ross, R.M. and Quetin, L.B., *Spawning frequency and fecundity of the Antarctic krill, Euphasia superba* (1983)
[27] Stevens, J.E., *The Secret lives of Krill* (1995)

cycle becomes somewhat more complicated. From the juvenile stage to adulthood is a matter of growth, acquisition of sexual characteristics and moults to accommodate for size (no new forms). That is not the complicated part. What is interesting is that these Krill appear to be able to moult back to the juvenile stage.

For many years the lifespan of the Antarctic Krill was thought to be only two years. This was based on analysis of population structure. In early spring researchers could go out with a trawler and sample the population. When this was done what was found was that the early season population largely consisted of juveniles suggesting a rapid population turnover[28]. However, a study done on Krill in captivity revealed that these crustaceans are able to survive for as long as 211days without food.[29] Subsequent studies revealed that during such starvation periods the Krill actually shrink in size. They are able to moult backwards losing their sexual characteristics and resembling juveniles[30]. The implication of this is that the early spring sampling containing largely juveniles is in actuality a mixture of new juveniles and adults that have regressed over a winter starvation period. This leaves a great big question mark over the issue of Krill longevity. Further laboratory based science involving captive Krill have produced figures for a lifespan as long as 11 years[31]. It is now widely accepted amongst researchers that if a Krill manages to evade predation it could live at least five years in the wild.[32]

[28] Nicol, S., The Age-old Problem of Krill Longevity (1990)
[29] Ikeda, T. and Dixon. P., *Body shrinkage as a possible overwintering mechanism of the Antarctic krill, Euphasia superba* (1982)
[30] Thomas, P.G. and Ikeda, T., *Sexual regression, shrinkage, re-maturation and growth in female Euphasia superba in the laboratory* (1987)
[31] Ikeda, T., *Life history of Antarctic krill Euphasia superba: a new look from an experimental approach* (1985)
[32] Stevens J.E., *The Secret lives of Krill* (1995)

More Unanswered Questions of Krill biology

Understanding certain aspects of the biology of a species is crucial to establishing proper management of the relevant fishery. The aim of Krill fisheries management is to ensure that the population is maintained at a certain level, preferably one with a minimum of ecological impact, while still allowing some level of catch. In order to find the magic number representing an upper catch limit some basic biological facts are needed. How many Krill are out there? Where are they? Is there one stock population throughout the Southern Ocean or many, mostly isolated, populations? How quickly can the Krill reproduce?

Many of the answers to these questions have eluded scientists. The problem of Krill longevity and the difficulty in establishing a population structure due to the Krill's unique wintering mechanism put a question mark over the reproduction estimates. Indeed, these estimates vary by a factor of ten from 135 million tons to 1.35 billion tons of Krill born annually[33]. The annual recruitment looked to be high until it was realised that a large number of the juveniles becoming adults were adults the year before. If the Krill can do this every winter and can live as long as five years (perhaps longer) in the wild then the recruitment rate (and birth rate based on population structure) may be 1/5 of what it appears to be.

The area in question is itself a barrier to finding the answers to these questions. The Krill are found over a huge area, up to 36 million km^2 [34], in the open ocean, and scientist must study their abundance and distribution from ships. The majority of the early sampling was a matter of net catches and while this did provide some idea of the gross distribution and relative abundance it did little in the way of providing small scale distribution patterns which would be of greater importance to Krill predators and indeed for the fishery. Modern techniques using echo-sound location give a better idea of the structure of Krill swarms but do

[33] Stevens, J.E., *The Secret lives of Krill* (1995)
[34] Nicol, S, de la Mare W, *Ecosystem management and the Antarctic Krill* (1993)

have their problems particularly regarding noise[35] (especially close to the ice edge). An idea of overall distribution can be gleaned from satellite imagery of phytoplankton densities (reasonably assuming an association between phytoplankton and Krill populations) but this is not useful for the small scale distributions. The size of the habitat is still the really limiting factor in determining just how much Krill there is in the Southern Ocean.

One Krill stock or many is another unanswered question with implications to the Krill fishery. Krill can be found throughout the Southern Ocean but that is a huge area for a single population. Because Krill are free swimming and therefore not at the mercy of the ocean currents, it is quite conceivable that there are geographically separate populations with enough crossover to prevent genetic isolation but not enough that if an area is depleted it is immediately replaced from other Krill stocks. If this is the case, then there is a risk of local fishing causing a collapse of the Krill stock in that area, and the associated implications up the food chain. There is evidence of natural variations resulting in local drops in Krill stocks, for example, in the vicinity of the peninsula, local warming has resulted in a reduction in the annual sea ice. The sea ice, in particular the algae trapped in the sea ice, is considered important to the survival of the immature Krill[36]. Along with the sea ice decline there has been an associated decline in the local Krill population[37]. The implication is of course that there can be localised population declines and area management of a Krill fishery could be of great importance.

The Southern Ocean Food Web

Why exactly are we so concerned with Krill? Of course we should always be concerned with the potential impact of a fishing industry but in the case of Krill the concern is much higher especially considering how small the fishery is at

[35] Ibid.
[36] Brierley, A.S., et al, *Antarctic Krill Under Sea Ice: Elevated Abundance in a Narrow Band Just South of Ice Edge* (2002)
[37] http://news.bbc.co.uk/1/hi/sci/tech/3979833.stm

present. The reason really comes down to the critical role that Krill plays in the Southern Ocean food web. (See Figures 5 and 6[38]). Krill are the major converters of biomass from the primary producers, the phytoplankton, up to the carnivorous predator species. There is a direct or one step removed reliance of all higher species on Krill as a food source[39].

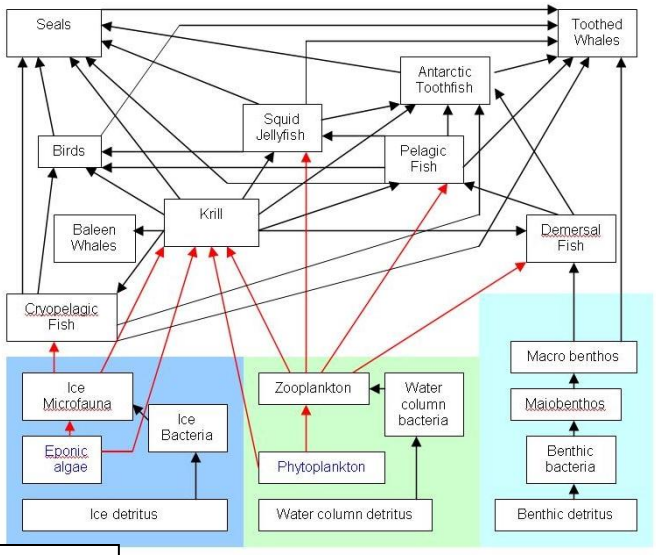


Figure 5

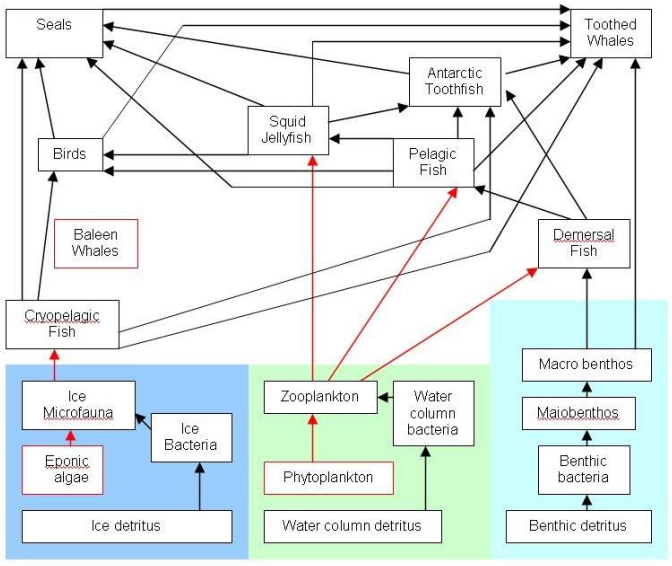


Figure 6

In Figures 5 and 6 the feeding lines from the primary producers through plankton into the upper food chain are indicated in red. In Figure 5, Krill has been removed from the picture.

The Baleen whales have essentially been cut off from the food chain. The primary producers now have limited flow through to the upper food chain.

A major part of the diet of squid, seals and seabirds is Krill. The demersal and pelagic fish are also large Krill consumers. By cutting Krill out, a major food source for predator species is eliminated as

[38] Food web images are based on food web from Matthew Bartholomew's presentation
[39] Nicol, S., de la Mare, W., *Ecosystem management and the Antarctic Krill* (1993)

well as a key biomass converter.

The Southern Ocean has experienced in the past the effects of exploitation by humans. Hunting of the seals, whales, fish etc. have all caused a disruption to the ecosystem. However these animals tend to be predator species higher up the food chain. Krill fishing targets a species that is particularly central to the Southern Ocean food web and the implications of over fishing this species are far reaching and potentially disastrous. Until the abundance and the biology of this species is better understood, there will be continued concern about the possibility of over fishing and the enormous damage it could cause to the Antarctic marine ecosystem.

An Overabundance of Krill

However, the looming disaster of over fishing of Krill may not, in fact, be so looming. At the moment there appears to be an overabundance of Krill, most likely due to the large scale exploitation of the great baleen whales. The effect this is having on the lower part of the food web is interesting. Copepods, small crustaceans a couple of millimetres long, are being out competed for phytoplankton by the Krill. Small fish, too small to eat the 6cm long Krill, would normally feed on the copepods but are finding their numbers diminishing due to lack of food. The fact that these alterations to the lower end of the food chain are not being transmitted up, emphasises the role that Krill must be playing in the diets of the predator species above it.

There is some talk as to the role a Krill fishery could play in reducing the Krill population and having a positive effect on the ecosystem. The fishing trawlers could take the place of the missing whales; they actually operate in a similar way, and at present, do not take nearly as much[40]. While it may be true that a Krill

[40] This attitude speaks volumes about human nature. We killed the whales so there is plenty of Krill for us to take.

fishing industry could indeed appear to have a positive effect on the ecosystem, this is a system that has already been disturbed by human exploitation of a number of species and having fishing vessels take the place of one such species, one for which we hope there is the potential for recovery could well be counter productive. Let us hypothesis, a profitable Krill industry is established and a considerable amount of Krill is being taken. Some proportion of what would have been taken by the missing whales but not so much to hinder their recovery. This may work to begin with but a crisis point will be reached eventually where the whale population has recovered enough that it finds itself competing with the Krill trawlers. What happens then? Will the fishery just reduce its catch to allow the whales to continue recovery?

Considering the current level of Krill fishing, the likelihood of global over fishing of Antarctic Krill enough to impact on Whale recovery rates is likely to be low. Figure 7[41] shows the tonnage of whales, fish and Krill caught in the Southern Ocean from 1920 to 1992. During the 50 year period representing the height of whaling, over 60 million tons of whale biomass was removed from the Southern Ocean, mostly in the form of Blue, Fin, Sei and Humpback whales. An average sized Fin whale, weighing about 60 tons may eat 1 ton of Krill a day.[42] So, crudely put, 60 million tons of whales could probably eat 1 million tons of Krill a day. More then the current Krill allowable catch for an entire season. If the Krill surplus is even 1/10 this number then there is plenty of Krill for a growing fishery, up to a point anyway.

While there are many important unanswered questions regarding the biology of the Antarctic Krill one thing is quite clear to scientists, there are a lot of Krill in the Southern Ocean but exactly how much is not known. Due to the importance of Krill in the ecology the establishment of a Krill fishing industry is not to be taken lightly and due to the continued mystery surrounding relevant areas of their

[41] Nicol, S., de la Mare, W., *Ecosystem management and the Antarctic Krill* (1993)
[42] American Cetacean Society - http://www.acsonline.org/factpack/finwhl.htm

biology an extremely precautionary approach is advised, however, even the most precautionary estimates of Krill stock and reproduction allow for a fishery larger then the present extent. The real issue is regarding the number of Krill stocks. A precautionary approach would say it is likely that there are geographically isolated populations and area over fishing could have a significant impact on the local ecology. Therefore, area Krill fisheries management may be the most important thing if we wish to avoid significant ecological impacts in the future.

Krill Products and Uses

Krill can be classified into three major uses:

- Food for Human Consumption
- Aquaculture Feed
- Nutraceutical Products

Food for Human Consumption

Although it is not the main product, Krill is manufactured for human consumption. It is prepared as frozen boiled Krill or frozen blocks of peeled Krill tail. Krill is advertised as being nutritional and as having a similar taste to crayfish. It can be used in soups, salads, pizzas and as restaurant entrees[43]. Studies have shown it to be rich in Omega 3 oils, vitamins, minerals and antioxidants[44]. There are also some cases of Krill being used as a paste, health food supplements (concentrated vitamin capsules) and as food additives (eg Krill oil gel capsules)[45].

Japan is the only country to give a formal indication of the kind of Krill products produced. Japan uses approximately 40% of its catch for human food consumption[46].

In the past, there have been problems with using and marketing Krill because unless it was shelved quickly, the high levels of fluoride in their shells spoilt the meat for human consumption[47]. However, processes have been found which significantly lower the fluoride and have brought Krill products into the market[48].

[43] Sclabos, D., *The Krill* (2003)
[44] Suzuki, T. and Shibata, N., *The Utilization of Antarctic Krill for Human Food* (1990)
[45] ed. Everson, I., *Krill: Biology, Ecology and Fisheries* (2000)
[46] Ibid.
[47] Budzinski, E., et al, *Possibilities of Processing and Marketing of Products made from Antarctic Krill* (1985)
[48] Nicol, S., and Endo, Y., *Krill Fisheries of the World* (1997)

Aquaculture Feed

The use of Krill as aquaculture feed has increased over the last five years, and looks to develop even more in the near future. It appears to be the most important and profitable market development in the Krill Industry.

In the last five years, there has been great concern that aquaculture feed demand is exceeding supply, and that the problem will intensify in the near future. The Fish Oil Manufacturers Association indicated that by 2010, 620 000 tons of fish oil will be needed to farm salmon and trout alone[49]. This concern has encouraged industries to seek alternatives, and has led to the increasing demand for Krill as aquaculture feed.

Furthermore, research has been conducted to show the unique features and benefits of Krill as fish feed. Sclabos & Toro (2003)[50] showed that Krill meal is an excellent nutritional source of protein, fat, energy and essential amino acids. They found it to be highly valued as being palatable and with a natural pigment content (most appropriate for salmon farming). Most importantly, it was reported that Krill meal stimulates feeding behaviour of some fish, is likely to improve larval fish survival, and that it has a low content of pollutants. These features led the researchers to label Krill as "irreplaceable…with unique nutritional and quality attributes, which makes it the feed ingredient of the future"[51].

On a smaller scale, Krill is also used for sport fishing bait and for the home aquarium market. 10% of the Japanese Krill catch used for fish feed, is used as chum for sport fishing, and a very small quantity for aquarium food[52].

[49] Staniford, D., *Cage Rage: an inquiry is needed into Scottish fish farming* (2001)
[50] Sclabos, D., Toro, R., *Natural Foods through Marine Krill Meal* (2003)
[51] Ibid.
[52] Nicol, S., and Endo, Y., *Krill Fisheries of the World* (1997)

Nutraceutical Products

Krill contains a comprehensive range of bio-chemicals which are of pharmaceutical, medical and industrial value. Apart from aquaculture feed, this is the other area of major development in the use of Krill. For example, 87.5% of patents for Krill medical products have been registered after 1988[53]. However, there is a belief that investment and development in Krill nutraceutical products will not be the main driving force for economic improvement in the Krill Fishery[54].

The main production in this area, is that of chitin and chitosan from Krill shells, and Krill enzymes. Chitin and chitosan are used for a wide variety of products, such as loudspeaker membranes and cholesterol lowering capsules. Krill concentrated capsules are being advertised as a health food supplement for people experiencing medical conditions; from growth and nutritional disorders to cancer and radiotherapy[55]. Studies have found an enzyme in Krill to develop drugs for several types of illnesses. The enzymes have been used in products, such as those used for treating necrotic tissue and as chemonucleolytic agents. Krill enzymes are even being developed to use in the restoration of works of art[56].

[53] Nicol, S., Foster, J., *Recent Trends in the Fishery for Antarctic Krill* (2003)
[54] ed. Everson, I., *Krill: Biology, Ecology and Fisheries* (2000)
[55] Ibid
[56] Nicol, S., Foster, J., *Recent Trends in the Fishery for Antarctic Krill* (2003)

Krill Fishery Economics

In the last twenty years, there has only been one published detailed economic analysis on Krill fishing[57]. The study was describing data from the Soviet Krill Fishery between 1977-1991, so there is no research to describe the current Krill Fishery economic situation. CAMMLR (2002) has acknowledged that there is little hard evidence to create a picture of the current economic State of the Krill Fishery. "More information needs to be developed on the current and potential markets for Krill products in order to better understand future trends in the Krill fishery"[58].

We do know that in general, the economic situation for Krill harvesting, is that it has high costs and low returns.

It is expensive and difficult to operate Krill fishing vessels that must journey to remote locations to access Krill. There are also operational difficulties, such as having to process the Krill quickly before spoiling, and having to remove the fluoride-rich Krill shells before they can be consumed by humans. These problems have all resulted in a low catch per unit effort, and have not allowed for the Krill Fishery to be a lucrative one[59].

However, there are strong indicators to show that an improvement in the economic climate of the Krill fishery is about to happen. There is an increase in the demand for Krill products, particularly for aquaculture feeds and to a lesser extent, nutraceutical products[60]. At the same time, we are seeing more fishing restrictions in the Northern Hemisphere, which is likely to put greater pressure on Antarctic Krill stocks[61].

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[57] Litvinov, F.F., *CPUE Indices used in Soviet Krill Fishery Statistics from 1977 to 1992 and their Possible Utility for Evaluation of Relative Changes in Krill Biomass* (2004)
[58] CCAMLR, *Report of the Twenty-First Meeting for the Commission* (2002)
[59] Nicol, S., *Time to Krill?* (n.d)
[60] Nicol, S., Foster, J., *Recent Trends in the Fishery for Antarctic Krill* (2003)
[61] Ibid.

There is also the recent breakthrough in Krill-processing technology, which was introduced at the last annual CCAMLR meeting a few months ago. For the last two years, the Vanuatu-flagged vessel, Atlantic Navigator has used a new fishing system where Krill are continuously pumped aboard without needing to bring the trawl aboard; allowing them to extend their haul duration for several days. This new technique is currently being used by a Norwegian vessel, Saga Sea. The new method will enable harvesting methods to be significantly more efficient and less costly[62].

All these factors indicate that a major improvement in the economic climate of the Krill Fishery is highly likely.

[62] CCAMLR, *Report of the Twenty-Fourth Meeting of the Commission* (2005)

Discussion

Do we understand enough about Krill harvesting?

There is a lack of good scientific data about aspects of Krill biology, abundance and distribution. Laboratory based science reveals confusing information about Krill, which conflicts with interpretations of what is seen in the wild. Estimations of Krill population differ by a factor of 10 from hundreds of millions to over a billion tons. There are also small scale distribution patterns of importance to predators and the fishery which are difficult to map due to the size of the area involved. The largest source of distribution and abundance data comes from the fisheries. The reason for this being they have taken the most samples. This results in data that is biased to the few areas that are the focus of the Krill harvest at the moment. Good conclusive scientific data is needed to ensure accurate models of impacts that a Krill fishery would have on the Southern Ocean.
This lack of conclusive information has slowed down the establishment of Krill fishery regulations by CCAMLR.

Nature of the fishing

Krill fishing in Antarctica occurs in the summer and coincides with the breeding highs of the major predator species. This means both trawlers and the larger predators compete to target Krill swarms. All studies of Krill populations indicate an abundance of Krill in the Southern Ocean but there is a very real risk of concentrated fishing resulting in local ecosystem collapse.

Another potential issue that arises from the nature of fishing management in the Southern Ocean is the formation of an Olympic fishery. At present, this is not an issue as catch is well below Total Allowable Catch (TAC) but the question arises what happens when this changes? CCAMLR has not issued quotas in any of the Southern Ocean fisheries. This indicates that when the TAC of Krill is reached

fishing will become concentrated at the beginning of the season as fishing vessels compete to gain the largest catch before the TAC is filled. This has impacts on Antarctic Krill's breeding patterns as they exhibit an ability to revert back to the juvenile stage over winter. The result of this is that early in the season there are no adults in the population and breeding does not start until sexual characteristics are reacquired. Hence early season harvests reduce breeding populations in Krill.

Localised Krill harvesting is central to an economic industry as the best techniques and knowledge of the area is established over several seasons. The return harvesting expeditions concentrate on areas where swarms and the sea floor bathymetry are known. This results in small scale intense depletions season after season which will become more intense as the industry expands. Current harvesting is concentrated in the south atlantic.

Is there too much Krill?

Evidence suggest that there are large stocks of Krill in the Southern Ocean and with the biggest Krill predator species being greatly depleted in number the implication of this is that there is a surplus. This surplus is seen in flow in effects in the food web such as copepod population decline and predator (such as seals and penguins) population increase. There is an ecosystem instability caused by these flow on effects.
The perceived abundance of Krill has the potential to put policy makers controlling the fishery in a non-urgent frame of mind.

Humans as Whales

The 'Humans as Whales' viewpoint is an attitude that arose in response to the Krill surplus. The argument being that the fishery could consume some of the Krill the missing whales would have predated. This may appear to rebalance the

system for a time. However, as mankind hopes for the recovery of the Baleen Whale populations the question raised by this attitude is; what happens when the crisis point is reached and the recovering whales find themselves competing with a successful Krill harvest?

The amount of Krill that whales would have eaten is huge compared to what we are taking out currently. Competition between the whales and a Krill industry would only become an issue if the Krill industry expands to some fraction of the whale consumption. If this was to occur it would become a very serious issue. CCAMLR purports an ecosystem approach to fisheries management, if the ecological demands on the target of the fishery changes will the fishery change to accommodate this?

Will CCAMLR be effective in regulating industry?

CCAMLR was established in response to fears surrounding the expanding Krill harvesting industry in the 1970's. There were fears that unfettered exploitation would impact the whole Antarctic ecosystem. However, there are no real regulations placed on the harvesting of Krill by CCAMLR. What regulations have been emplaced has been the result of limited scientific data. CCAMLR makes decisions based on scientific recommendations but the State of scientific conclusions on aspects of Krill biology is suspect.
Although data is collected on Krill there is no control in place to ensure consistency of collection therefore it is scientifically unreliable.

Efforts to date made by CCAMLR to increase data collection such as the observer on vessels has meet resistance by a small few members. Changes to regulations are difficult due to the slow consensus approach and the differing values placed on the Krill industry by the individual members needs and wants. Although the object of CCAMLR is an ecosystem approach political factors seem to weigh heavily on how and why decisions are made.

There is an underlying conflict of interest in CCAMLR's objectives of ecosystem approach and the existence of fisheries industry in the Southern Ocean. Humans are not a natural part of the Southern Ocean ecosystem.

Will there be an expansion of the Krill Fishery?

Economic and logistical problems have restricted expansion of the Krill industry to date. These include a low catch per unit effort, few uses and low product value. Expansion of the Krill industry relies on an improvement in the associated economics. There are strong indicators for an improvement in the economic climate of the Krill Fishery. These include the recent breakthrough in the technology used to fish Krill by the Norwegian fishing industry, and the development of how Krill is used and marketed in aquaculture, medical and industrial areas. As the economics of Krill harvesting improve, the industry will continue to grow.

There has been an increase in restriction of access to Krill in the Northern Hemisphere, this is likely to result in an increase in interest in the Krill harvesting in Antarctic waters. In addition, the view that there is a massive abundance of Krill in the Antarctic waters acts as an incentive for greater investment in Krill harvesting.

It is highly likely these factors will become major economic justifications for the expansion of Antarctic Krill fishing.

Should we be concerned about the re-emergence of the Krill harvesting industry?

Reason why we may not be concerned

The current situation with Krill fishing in the Southern Ocean is of little concern. The harvest is well within sustainable catch limits of even the most precautionary views on the abundance and fecundity of Antarctic Krill. The take is under current catch limits, which suggests that the economics at this stage are not particularly good.

Total catches have remained stable in the range of 100,000 to 160,000 tonnes per season for the last 5 years. This implies that the technological limitations and demands of market forces, despite an increase in product use, will be regulating influences on the Krill industry.

Reasons why we are concerned

Krill is the central species in the Southern Ocean food web. Previous fisheries resulting in over exploitation have generally targeted predator species and the food web implications are limited. This is not the case with Krill. No matter how much Krill surplus there may be, the fact remains; we must remain concerned about a fishery involving a species so central to the food web and the overall ecology of the Southern Ocean.

Even if there are sufficient Krill in the Southern Ocean to support a significantly larger fishery there is concern regarding the ecological effects of localised over fishing especially considering the scarcity of knowledge regarding the small scale distribution of the Krill.

There is not enough regulation currently in place to manage a competitive Krill industry and there is an attitude that as it is not a problem now we do not have to

worry about it. CCAMLR needs to continue to work at not being responsive but pre-emptive. CCAMLR is currently undertaking scientific research in order to put legislation in place, but this process ought to be sped up if CCAMLR wants to be pre-emptive about the Krill industry. Just because it is not a problem at the moment, does not mean it will not become one in the future, particularly considering future market indicators of an expanding krill industry. Avoiding an ecosystem collapse is much better then reacting to it once it is occurring. In addition, it is much easier to set regulations early on. If the fishery becomes accustomed to certain behaviors, changing those behaviors will be met with resistance.

There are also some concerns regarding the 'too much Krill' attitude and the idea of humans as whales. Humans are not a normal part of the Southern Ocean ecosystem and it is worth remembering that, if we want to take an ecosystem approach to fishing.

Mankind does not have a good track record in regards to sustainable management of fisheries in the Southern Ocean. The traditional boom and bust result of fisheries in the Southern Ocean has set a precedent of harvesting trends followed by most major industry members. Despite efforts by CCAMLR the Toothfishing industry has shown the same trends, which suggests an inability to mitigate this by CCAMLR in modern fisheries as well.

Conclusion

There is a reasonable argument for the existence of the Krill fishery. If it is valuable and can be managed with an ecosystem approach then there is no reason that it should not exist. However, considering the importance of the species in question and the limited amount of knowledge a significantly greater degree of regulation should be instituted before the fishery expands.
A more precautionary attitude towards the possibility of expansion, the changing economics, and the science would help to avoid future problems.

CCAMLR is the managing body for fisheries in the Southern Ocean. It was hailed as forward thinking and revolutionary but has yet to implement any significant management procedures to do with an increasingly important Krill industry. To have better management practices in the future CCAMLR needs to adopt an adaptive pre-emptive approach to potential issues raised by the Krill harvesting industry. Actions that need to happen now include the initiation of a comprehensive Sub-area management program for the 15 sub areas defined in 2002. The basis of CCAMLR's management practices are from scientific models of what would constitute a sustainable yield for a single season. It is understood that these models are only as good as the data they are based on an further encouragement of independent science expeditions on krill research are required for appropriate management. Having said this, the present models must be based on the most precautionary data available to mitigate future management problems. If the ecosystem is in a State of flux then the management also needs to be in a State of flux.

The Southern Ocean is a recovering ecosystem. It is not stable and we cannot assume it will remain the same forever. The reliance of the Krill surplus as a justification for a larger fishery should naturally be followed at a later date by the recovery of the whale population as a reason to reduce the fishery. The question

is, will it be? This is the sort of question that needs to be asked and answered now, not in the future when it may be too late.

Krill is too important not to think about future ramifications. The last thing we want is to be surprised in 100 years by a Southern Ocean ecosystem collapse.

Final comment

The Krill industry at its current levels of impact is of little concern. However the changing economic climate surrounding the industry is cause for forward thinking on the potential issues that will arise from an increased removal of Krill from the Southern Ocean ecosystem.

Appendices

Krill Recipes

Krillion Patties

2 cups Krill
2 tablespoons butter
salt and freshly ground pepper
2 heaped tablespoons flour
2 cups milk celery
1/2 red capsicum (pepper)
1/2 onion
1 small carrot
1 bay leaf
pinch basil
drop Tabasco sauce
slices of bread
parsley, chopped
lemon wedges
patty tins (2 dozen)

Wash Krill in a fine mesh strainer under a running tap. Pat dry with a tea towel. Melt butter in a saucepan, add salt and pepper and stir in flour until it forms a ball. Gradually add 1 cup of the milk, stirring constantly to prevent sticking or burning. Add remaining milk, stirring all the time. Blend vegetables and herbs in a blender and add to sauce with Tabasco. Butter bread slices very thickly, press into patty tins and bake in a hot oven for 15 minutes, Add Krill to sauce and cook slowly for five minutes to allow the sauce to absorb the flavour of the Krill. Fill bread cases with sauce, sprinkle with parsley and paprika, and serve hot with lemon wedges.

Serves 4

Links To Patagonian Toothfish Fishery

There has been an increase in the demand for Patagonian Toothfish (*Dissostichus eleginoides*) since the early 1990s. It is a high quality fish with a profitable market; fetching US$40-60/kg. Consequently, there has been a significant increase in the number of legal and IUU (Illegal Unregulated and Unreported) fishing vessels operating in Antarctic waters; posing a serious threat to the protection of marine living resources, such as the Patagonian Toothfish and bycatch[63].

There are mixed views as to whether the Krill industry is in the early stages of going down the same pathway as the Toothfish Fishery.

Clark and Hemming (2001) voice strong concerns on this subject: "The Fishery of Patagonian Toothfish has posed the most significant environmental damage on the Antarctic environment in modern times…and threatens to be repeated in the second-generation Krill fishery that is rapidly developing"[64].

Futhermore, similar to the Toothfish situation, there is data to indicate that the bycatch of fish, such as icefish (*Champsocephalus*) in the Krill Fishery may be significant in some areas of the South Georgia shelf[65].

There are also concerns that some current defiance to Krill Fishery policies, could indicate the beginning of the repeat of the threats we are seeing from IUU fishing on Toothfish. For example, CCAMLR has encouraged the placement of

[63] Lack, M., Sant, G., *Patagonian Toothfish: are Conservation and Trade Measures* (2001)
[64] Clark, C., Hemmings, AD., *Problems and Prospects for the Convention on the Conservation of Antarctic Marine Living Resources Twenty Years On* (2001)
[65] Everson, E., et al. *Bycatch of Fish in the South Atlantic krill Fishery* (1992)

international observers on Krill vessels, but this has been met with some resistance. A lack of data reporting cooperation has also been noted[66].

However, a strong argument and possibly most accepted, is that there is no immediate concern for the Krill Fishery mirroring the Toothfish, because the current economics are so different. Toothfish is a lucrative market, unlike the Krill market. Krill Fishery economics must improve for industry to increase.

[66] Clark, C., Hemmings, A.D., *Problems and Prospects for the Convention on the Conservation of Antarctic Marine Living Resources Twenty Years On* (2001)

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<http://www.aquafeed.com/article.php?id=365>

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Food web images based on food web from Matthew Bartholomew's presentation